



UNIVERSITI PUTRA MALAYSIA

**ESTIMATION OF CARBON STOCK AND EMISSION, AND LIFE
CYCLE ASSESSMENT OF MALAYSIAN HEVEA FOR
ESTABLISHING NATIONAL CARBON INVENTORY**

IRENE CHUNG.

FSAS 2004 24

**ESTIMATION OF CARBON STOCK AND EMISSION, AND LIFE CYCLE
ASSESSMENT OF MALAYSIAN *HEVEA* FOR ESTABLISHING NATIONAL
CARBON INVENTORY**

By

IRENE CHUNG

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in
Fulfilment of the Requirements for the Degree of Master of Science**

June 2004

Thesis Supervisor



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

**ESTIMATION OF CARBON STOCK AND EMISSION, AND LIFE CYCLE
ASSESSMENT OF MALAYSIAN *HEVEA* FOR ESTABLISHING NATIONAL
CARBON INVENTORY**

By

IRENE CHUNG

June 2004

Chairman: Associate Professor Mohd. Ismail Yaziz, Ph.D.

Faculty : Science and Environmental Studies

The study utilises two computer spreadsheet models to estimate both carbon sequestered by Malaysian rubber plantation ecosystems, and carbon stocks and emissions from harvested rubber wood products (furniture, medium density fibreboard, rubber gloves and tyres). Changes in the net carbon balance in Malaysian rubber ecosystems are related to the total rubber hectarage, age class structure, age class dynamics, and total biomass, rate of harvesting and production and utilization of the products. The Carbon Sequestration Model and Harvested Wood Products Model were used to estimate the carbon budget of the ecosystem and also the carbon fate in the latex and wood products throughout their life span. From the life cycle assessment of one-hectare of rubber, we

project that carbon storage in biomass and products could last up to 63 years before it returns to a carbon neutral situation. At the national level, the rate of carbon stocks were projected to decrease from 241,748 kTC in 1991 to 231,541 kTC in 1996. The declining trend (between 1991 and 1996) was estimated to continue in the projected years (2004 to 2020). Carbon stocks registered at 105,354 kTC (year 2013), followed by 90,748 kTC (year 2017) and eventually amounted to 80,797 kTC (year 2020). Harvested rubber products played an important role in the process of delaying the return of the carbon to the atmosphere. Net emission could be minimized through appropriate pollution control technologies in landfills, increasing product use efficiency, recycling and increasing product longevity. Stock to emission ratio (SER) is described and proven to be a useful measure to determine the longevity of an industry.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**ANGGARAN STOK KARBON DAN PELEPASANNYA, DAN LCA HEVEA DI
MALAYSIA UNTUK PEMANTAPAN INVENTORI KARBON NASIONAL**

Oleh

IRENE CHUNG

Jun 2004

Pengerusi: Profesor Madya Mohd. Ismail Yaziz, Ph.D.

Fakulti : Sains dan Pengajian Alam Sekitar

Kajian ini telah mengutilasikan dua simulasi perisian komputer, Carbon Sequestration Model dan Harvested Wood Product Model untuk menganalisis kemampuan penanaman getah di Malaysia dengan membandingkan kadar penyerapan dan pelepasan karbon dalam ekosistem tanaman getah berserta hasil produknya (perabot, MDF, sarung tangan getah dan tayar). Perubahan keseimbangan ini adalah berkait rapat dengan jumlah keluasan tanaman, pengkelasan tanaman mengikut peringkat umur, jumlah berat kering tanaman, kadar penuaian tanaman serta jumlah produktiviti dan penggunaan produk tanaman getah. Melalui kajian kitaran satu hektar, dapat disimpulkan bahawa simpanan karbon yang terdapat di ekosistem dan produk tanaman akan berlanjutan sehingga 63 tahun sebelum keadaan menjadi karbon neutral semula. Apabila konsep simulasi diaplikasikan ke senario sebenar penanaman getah di Malaysia, kajian mendapati jumlah stok karbon adalah berkurangan dari 241,748 kTC pada tahun 1991

hingga 231,541 kTC pada tahun 1996. Kadar penurunan ini juga akan mempengaruhi jumlah stok karbon sehingga tahun 2020. Dari 105,354 kTC pada tahun 2013, jumlah stok berkurangan sehingga 90,748 kTC pada tahun 2017 dan akhirnya pada tahun 2020, jumlah stok adalah 80,792 kTC. Produk hasil dari tanaman getah memainkan peranan penting dalam melengahkan masa pengembalian karbon ke atmosfera. Kadar pelepasan karbon ke atmosfera dapat dikurangkan melalui penggunaan teknologi kawalan pencemaran di tapak pelupusan, peningkatan peratus utiliti produk, kitar semula serta peningkatan jangka hayat produk. Pengiraan nisbah antara jumlah stok dengan pelepasan karbon adalah penting dalam menentukan kepanjangan sesuatu industri.

ACKNOWLEDGEMENTS

I would like to seize this opportunity to thank my Thesis Supervisory Committee, Prof. Madya Dr. Mohammad Ismail Yaziz, En. Azman Zainal Abidin and Dr. Yew Foong Kheong for the helpful guidance and support along the way. Your genuine act was very meaningful to me in helping me to pull through. I really appreciate that.

Next, my deepest appreciation to Dr. Gary W. Theseira (FRIM) for providing the priceless kindness of guidance, supervision and advice. We went through these together and your assistance and support meant a lot to me. Thanks, you are a friend.

I feel eternal gratitude to Puan Hajah Nor Aisah Abd. Aziz (Technical Advisory Unit), En. Mohd. Johari Mohd. Hassan (Head of Planning and Production of Economic Unit), En. Abd. Halim Hassan (Head of Industrialization Planting Unit), Pn. Fauziah Abd. Rahman (Chef Librarian) and Pn. Haji Zulkifili Mohd. Nazim (Pengarah Bahagian Perancangan Strategik RISDA), for their generous co-operation in giving essential information for the study.

Not to forget, my sincere gratitude to Prof. Dr. Ahmad Makmom (UPM) and Prof. Dr. Ramdzani Abdullah (UPM) for their valuable assistance, guidance and encouragement.

To everyone else involved in this study, my sincere thankfulness to all of you. You're not forgotten. Thanks again.

I certify that an Examination Committee has met on 3rd June, 2004 to conduct the final examination of Irene Chung on her Master of Science thesis entitled “Estimation of Carbon Stock and Emission, and Life Cycle Assessment of Malaysian *Hevea* for Establishing National Carbon Inventory” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Firuz Mohammad Ramli, Ph.D.

Faculty of Science and Environmental Studies
Universiti Putra Malaysia
(Chairman)

Ramdzani Abdullah, Ph.D.

Faculty of Science and Environmental Studies
Universiti Putra Malaysia
(Member)

Ahmad Makmom, Ph.D.

Faculty of Science and Environmental Studies
Universiti Putra Malaysia
(Member)

Mohd. Rashid Mohd. Yusof, Ph.D.

Associate Professor
Department of Chemical Engineering
Faculty of Chemical & Natural Resources Engineering
Universiti Teknologi Malaysia
(Independent Examiner)



GULAM RUSUL RAHMAT ALI, Ph.D.

Professor/Deputy Dean
School of Graduate Studies,
Universiti Putra Malaysia

Date: 26 AUG 2004

This Thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirements for the degree of Master of Science. The members of the Supervisory Committee are as follows:

Mohammad Ismail Yaziz, Ph.D.

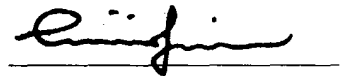
Associate Professor
Faculty of Science and Environmental Studies
Universiti Putra Malaysia
(Chairman)

Azman Zainal Abidin,

Faculty of Science and Environmental Studies
Universiti Putra Malaysia
(Member)

Dr. Yew Foong Kheong, Ph.D.

Crop Management Unit
Stesen Penyelidikan LGM Sungai Buloh
47000 Sungai Buloh
Selangor
(Member)



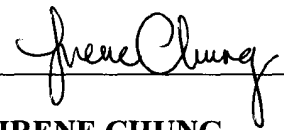
AINI IDERIS, Ph.D.

Professor/Dean
School of Graduate Studies,
Universiti Putra Malaysia

Date: 10 SEP 2004

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently for any other degree at UPM or other institutions.


IRENE CHUNG

Date: 25 AUG 2004

TABLE OF CONTENTS

	Page
ABSTRACT	ii
ABSTRAK	iv
ACKNOWLEDGEMENTS	vi
APPROVAL	vii
DECLARATION	ix
LIST OF TABLES	xiii
LIST OF FIGURES	xiv
LIST OF SYMBOLS AND ABBREVIATION	xv
 CHAPTER	
 I Introduction	
1.1 Global Climate Change	1.1
1.2 Carbon Sinks	1.4
1.3 Importance of Carbon Sinks	1.5
1.4 Rubber and Carbon Sinks	1.6
1.5 The Carbon Budget and Life Cycle Assessment of a Rubber Plantation	1.8
1.6 Objective	1.12
1.7 Significance of Study	1.13
 II Literature Review	
2.1 Malaysia and Greenhouse Gasses	2.1
2.2 Greenhouse Gasses Inventory by Agriculture Sector	2.3
2.3 Malaysia's Greenhouses Gasses Emissions	2.4
2.4 Malaysian Forests and the Carbon Cycle	2.5
2.5 Carbon Pools and Forestry Management Strategies	2.6
2.6 The Origins of Rubber	2.7
2.7 <i>Hevea brasiliensis</i>	2.8
2.8 Clone PB 260	2.10
2.9 Rubberwood	2.11
2.9.1 Uses of Rubberwood	2.12
2.9.2 Yield of Rubberwood Per Hectare	2.13
2.9.3 Processing Mills	2.14
2.9.4 Potential Growth of Rubberwood	2.15
2.10 Natural Rubber Latex	2.16
2.10.1 Uses of Natural Rubber	2.17
2.10.1.1 Gloves	2.17
2.10.1.2 Tyres	2.18
2.10.2 Production of Natural Rubber in Malaysia	2.18



2.11	Carbon Sequestration Studies in Rubber	2.19
2.11.1	Carbon in Tree Biomass	2.20
2.11.2	Annual Leaf Fall	2.21
2.11.3	Carbon in Annual Branch Fall	2.22
2.11.4	Carbon in Seed Fall	2.22
2.11.5	Carbon in Latex and Cuplumps	2.22
2.12	Computer Models	2.23
III	Materials and Methods	
3.1	Materials	3.1
3.2	Research Procedures	3.2
3.2.1	Carbon Sequestration Model	3.2
3.2.2	Business As Usual (BAU) Scenario	3.3
3.3	Worksheet I – Age Class Structure	3.3
3.3.1	Operations Performed in Worksheet I – Age Class Structure	3.5
3.4	Worksheet II – Biomass Inventory	3.9
3.4.1	Operations Performed in Worksheet II – Biomass Inventory	3.9
3.5	Worksheet III – Rubber Products	3.10
3.5.1	Rubberwood	3.11
3.5.2	Latex	3.12
3.5.3	Operations Performed in Worksheet III –Products	3.14
3.6	Harvested Wood Products	3.16
IV	Results	
4.1	Carbon Stocks Sequestered Over the Life Cycle of One-Hectare Of Hevea	4.1
4.2	Emissions from Carbon Stocks Over the Life Cycle of One-Hectare Of Hevea	4.7
4.3	Malaysian Hevea in Age Class Structure	4.11
4.4	Total Biomass in Malaysian Hevea	4.14
4.5	Production of Furniture and MDF	4.17
4.6	Production of Gloves and Tyres	4.19
4.7	Carbon Stocks Sequestered Over the Life Cycle of Malaysian Hevea	4.21
4.8	Emissions from Carbon Stocks Over the Life Cycle of Malaysian Hevea	4.25
V	Discussion	
5.1	The Role of Malaysian Hevea and Harvested Wood Products	5.1
5.2	Opportunity for Harvested Wood Products	5.2
5.3	Issues Associated With Harvested Wood Products	5.3
5.3.1	Harvest and Utilization Efficiency	5.4
5.3.2	Product Longevity	5.5
5.3.3	Recycling	5.6
5.4	Stock to Emission Ratio (SER)	5.6

VI	Conclusion	6.1
REFERENCES		R.1
APPENDICES		A.1
BIODATA OF THE AUTHOR		B.1



LIST OF TABLES

Table	Page
1.1 Annex I Countries To The United Nations Framework Convention On Climate Change	1.3
2.1 Summary of National Greenhouse Gas Emissions and Removal in 1994	2.2
2.2 Emissions and Removal of Greenhouse Gasses for Each Sector in 1994	2.3
2.3 GHG Emissions of Selected Countries	2.4
2.4 Distribution of PB 260 According to State in 1996	2.11
2.5 Estimate of Wood Production	2.13
2.6 Status of Rubberwood Processing Industry in Peninsular Malaysia 1992	2.14
2.7 Malaysia's Rubber Production, 2001 and 2002 by Regions and Sectors	2.19
2.8 Dry Matter Production of Rubber Trees According to Age	2.20
2.9 Dry Matter and Carbon Content of Rubber Trees At Felling	2.21
2.10 Estimated Carbon Fixed in Annal Leaf Fall Litter	2.21
2.11 Amount of Carbon Fixed in Latex and Cuplumps	2.22
3.1 Decision Table	3.7
3.2 Recovery Rate of Furniture and MDF	3.12
3.3 Parameter Settings for the HWP's Model Used in the Simulation of Stocks and Emissions From Rubber Products	3.16



LIST OF FIGURES

Figure	Page
1.1 Carbon Emission of Rubber and the End Products	1.11
3.1 Proportion of Branch, Trunk, Twigs and Leaves of a Rubber Tree	3.11
3.2 Flow Chart of the Whole Process of the Modeling Work	3.17
4.1 Carbon Stocks Sequestered Over the Life Cycle of One-Hectare of Hevea	4.3
4.2 Emissions from Carbon Stocks Over the Life Cycle of One-Hectare of Hevea	4.8
4.3 Rubber Plantation Hectarage in Age Class Structure	4.12
4.4 Total Biomass Content in Rubber Plantation in Age Class Structure	4.15
4.5 Production of Furniture and MDF	4.18
4.6 Production of Tyres and Gloves	4.20
4.7 Carbon Stocks Sequestered Over the Life Cycle of Malaysian Hevea	4.22
4.8 Emissions from Carbon Stocks Over the Life Cycle of Malaysian Hevea	4.26
5.1 Stock to Emission Ratio (SER)	5.8

LIST OF SYMBOLS AND ABBREVIATION

C	carbon
CDM	Clean Development Mechanism
CERs	Certified Emission Reduction
CH ₄	methane
CO ₂	carbon dioxide
COMAP	Comprehensive Mitigation Assessment Process
EWPs	engineered wood products
Gg	gigagram
GHG	greenhouse gasses
GWP	Global Warming Potential
HFCs	hydrofluorocarbons
HWPs	Harvested Wood Products
IPCC	International Panel on Climate Change
kT	kilo tonne
LTC	latex timber clone
LVL	laminated veneer lumber
MDF	medium density fibreboard
MRB	Malaysian Rubber Board
N ₂ O	nitrous oxide
PFCs	perfluorocarbons
RRIM	Rubber Research Institute of Malaysia
SER	stock to emission ratio
UNFCCC	United Nations Framework Convention on Climate Change

CHAPTER I

INTRODUCTION

1.1 Global Climate Change

Climate change is a widely considered to be one of the largest threats to the sustainability of the Earth's environment, and the well being of its people. Most scientists agree that the Earth's climate is changing from the buildup of greenhouse gases (GHG), principally carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) that result from anthropogenic activities such as electricity generation, transportation, and agriculture (Houghton et al., 1990). CO₂ is the primary GHG and its concentration in the atmosphere has been increasing steadily since 1958 (Keeling et al., 1989). Predictions of future climate change caused by increasing atmospheric CO₂ and its potential effects on human environment and health have led to international concerns about the production of GHG (Houghton et al., 1995).

The global carbon cycle is the most important process linking forests to climate change. Forests play an important role in the global carbon cycle because they store a large amount of carbon in vegetation and soil, exchange carbon with the atmosphere through photosynthesis and respiration, are atmospheric (sinks during regrowth after disturbance, and become a carbon source when they are disturbed by human activity or

natural causes (e.g., forests fires, insect outbreaks, harvesting) (Dixon et al., 1994, Steffan et al., 1998). Through forest management, people can change (the amount of carbon stored in a) forest ecosystem (pools and fluxes), and thus affect atmospheric CO₂ concentrations (Apps and Price, 1996).

The international response to climate change includes the United Nations Framework Convention on Climate Change (UNFCCC). Agreed to in 1992, the Convention is a framework for action to limit or reduce GHG emissions. In 1997, 159 countries signed the Kyoto Protocol, committing industrialized countries to reducing their GHG emissions.

Article 12 of the Kyoto Protocol allows developed countries and countries with economies in transition, so-called Annex I (see Table 1.1), to meet their greenhouse gas reduction commitments by engaging in what is called the “Clean Development Mechanism (CDM)”. Developing countries that have ratified the Kyoto Protocol, or non-Annex I countries, can benefit from these CDM projects to promote sustainable development. Annex I countries receive certified emission reduction (CERs) credits for investing in projects that result in additional reductions in the emissions of GHG in developing countries. Ideally, CDM projects should involve the transfer of and investment in environmentally safe technologies and practices.

Greenhouse gases mix evenly in the atmosphere making it possible to reduce emissions at any point on the planet and have the same effect. This fact enables countries to pursue GHG reductions wherever they can be reduced at lower costs. CDM

projects allow developed countries that have ratified the Kyoto Protocol to invest in projects that reduce GHGs in developing countries while contributing to sustainable development. Approved and certified projects can earn certified emission reductions (CERs) that developed countries can use to meet their Kyoto Protocol GHG reduction commitments and to contribute to the overall goal of mitigating climate change. CDM projects help developed and developing countries work together to achieve sustainable development and decrease GHG emissions through the Kyoto Protocol.

Table 1.1: Annex I Countries To The United Nations Framework Convention on Climate Change

Annex I or Investor Countries*			Sectors	Greenhouse Gases and Gas Classes
Australia	Greece	Poland	Energy	Carbon dioxide (CO ₂)
Austria	Hungary	Portugal	Industrial Processes	Methane (CH ₄)
Belarus	Iceland	Romania		
Belgium	Ireland	Russian Federal	Solvent and other product use	Nitrous oxide (N ₂ O)
Bulgaria	Italy	Slovakia		
Canada	Japan	Spain	Waste	Hydrofluorocarbons (HFCs)
Croatia	Latria	Sweden		
Czech Republic	Liechtenstein	Switzerland	Land use, land use change, forestry	Perfluorocarbons (PFCs)
Denmark	Lithuania	Turkey		
Europe	Luxembourg	Ukraine		
Estonia	Monaco	United Kingdom		
Finland	Netherlands	United States of America		Sulphur herafuorid (SFs)
France	New Zealand			
Germany	Norway			

*These countries need to ratify the K.P in order to use the CDM mechanism, Entities in these countries – whether public or private- constitute the investors in CDM

Source: Kyoto Protocol, Annex A

1.2 Carbon Sinks

The term “sink” is commonly used to describe the carbon taken from the atmosphere by plants and stored in living and dead organic matter both above and below ground in land-based (or *terrestrial*) ecosystems.

Forests remove CO₂ from the atmosphere and store carbon in plant material and soil. This natural process is part of the carbon cycle and is known as sequestration. Approximately half of a tree’s dry mass is carbon, so large amounts of carbon are stored in forests and they are the largest store of terrestrial carbon. (Apps and Price, 1996). Depending upon the particular forest, the amount of carbon stored in it may be; increasing – making the forest a carbon sink, decreasing – a carbon source, or in carbon balance – a carbon store.

Other ecosystems such as savannas and woodlands are also significant sinks. In most ecosystems, the majority of the carbon is stored below ground, either as roots and decaying biomass or as organic carbon in soil (De Jong et al., 2000).

Forests can absorb CO₂ from the atmosphere and thereby assists us by temporarily stabilizing greenhouse gasses in the atmosphere. However, half of the world’s forests have already been cleared and those that remain have largely been degraded. We have therefore reduced the capacity of the world’s forests to slow climate change.

1.3 Importance of Carbon Sinks

According to a report by Houghton et al., (1998), the concentration of CO₂ in the atmosphere is increasing. Human activity has continued to release large amounts of CO₂, largely from the burning of fossil fuels (oil, gas and coal) and from activities such as clearing forests. Each year, human activities are thought to add an extra 7 billion tonnes of CO₂ to the atmosphere.

Because CO₂ traps heat in the atmosphere, increasing concentrations of CO₂ will lead to global climate change. Many scientists predict that climate change will result in more extreme weather patterns – more cyclones, floods and droughts. With such changes in our climate, rising sea levels will threaten coastal environments, it will be harder to grow food successfully, and the rate of species extinction will increase.

Houghton et al., (1998) also stated that, to reduce the impacts of climate change, it is necessary to stabilize atmospheric CO₂ concentrations. In the 250 years since the industrial revolution, the amount of CO₂ in the atmosphere has increased by 30%. To stabilize CO₂ at current levels, we need to reduce emissions by 50% - 70% now. To stabilize CO₂ at twice pre-industrial levels, emissions need to be reduced by 30% now. Forest carbon sinks can help us to do this through the natural absorption and storage of carbon dioxide.

An international agreement, the UN Framework Convention on Climate Change (UNFCCC) was ratified in 1994. The UNFCCC aims to stabilize atmospheric Kyoto Protocol pursues action (if and when ratified), to combat global warming by managing greenhouse gas sources and sinks.

Under the Kyoto Protocol, developed countries have set emissions reduction targets that are on average 5% below 1990 levels. There are a number of mechanisms in the Protocol, including carbon trading that can help Annex I countries reach their emissions reduction targets

1.4 Rubber and Carbon Sinks

Carbon sequestration by agricultural land has generated international interest because of its potential impact on and benefits for agriculture and climate change where proper soil and residue management techniques are implemented, agriculture can be one of many potential solutions to the problem of greenhouse gas emissions. Additionally, agricultural conservation practices such as the use of different cropping and plant residue management, as well as organic management farming, can enhance soil carbon storage. Farmers, as well as the soil and environment, receive benefits from carbon sequestration.

Lal et al., (1995) reported that agricultural ecosystems represent an estimated 11% of the earth's land surface and include some of the most productive and carbon rich soils.

As a result, they play a significant role in the storage and release of carbon within the terrestrial carbon cycle.

Hevea like other green plants can be considered as a plant factory for solar energy conversion and a carbon sink by virtue of the process of photosynthesis. The maximum rate of photosynthesis, which differs between clones, has been recorded with a range from $1.14 \text{ mg m}^{-2} \text{ s}^{-1}$ in clone PR 107 to $0.36 \text{ mg m}^{-2} \text{ s}^{-1}$ in clone RRIM 623 (Cuelemans et al., 1984).

A monoculture of Hevea has been reported to be a relatively efficient converter of solar energy into dry matter. According to Templeton (1969), the rate of dry matter production of 5 ¼ and 6 ¾ years stand of RRIM 501 was 35.5 tonnes/hectare/year, a relatively high value among tree species. At this rate of dry matter production, the efficiency of utilization of solar radiation in a stand of Hevea trees with a closed canopy was calculated to be about 2.8% (Templeton, 1969).

Naimah, Zainol and Yoon (1992) also reported that Hevea trees have the highest photosynthetic productivity and with a capacity to fix 90 million tonnes of carbon per year. It would appear that a rubber plantation would be nearly as effective during photosynthesis as a virgin forest in consuming the products of fossil fuel burning as well as producing life sustaining oxygen.

The influence of the rubber trees on the atmospheric carbon balance is also indicated by the amount stored in biomass. The amount of biomass estimated for humid tropical forests in various countries ranged between 210 t/ha in Mulu, Malaysia and 664 t/ha in Pasoh, Malaysia. Rubber ecosystem at tappable maturity attain a relatively much lower biomass level than a mature forest ecosystem. However, with time the value for the rubber ecosystem increases. It reaches comparable levels at an age of beyond 30 years. The biomass potential of a 33 year old stand of tapped trees was 444.9 t/ha, a value nearing those obtained for forest ecosystems in Brazil and Malaysia, or even higher than those recorded in Thailand and New Guinea (K. Sivanadyan and Norhayati, 1992).

1.5 The Carbon Budget and Life Cycle Assessment of a Rubber Plantation

A carbon budget (sometimes called carbon balance) shows the inventory of carbon in carbon pools and the balance of exchange between the pools. The rate of exchange between the pools is called carbon flux. The most direct method of tracking the amount of carbon ecosystems for policy analysis is the calculation of carbon budgets based on biomass inventories. Many researches had considered rubber tree as a plant factory for solar energy conversion and carbon sink by virtue of the process of photosynthesis.

The influence of the rubber trees on the atmospheric carbon budget is also indicated by the amount stored in the biomass, with values comparable to that of forest ecosystems, particularly beyond a certain age of growth.

Rubber plantation plays an important role with regard to carbon contribution to the environment. In recent years, net addition or sequestration carbon in Malaysia in one hectare of a 27 year-old stand of rubber trees is 72.36 tonnes. The total amount of carbon sequestered in one hectare of rubber trees made up of tree biomass, latex produced and leaf litter is computed to be 319 tonnes (Sivakumaran et. al., 1992).

Life-cycle assessment evaluates a product or activity through all of its stages, from raw material access through manufacturing to consumer use and waste management (recycling or disposal). This concept is often referred to as a cradle-to-grave assessment. Life-cycle assessment require detailed data on production, extraction (harvesting) and processing of raw materials, manufacturing, use and disposal.

Rubber products also play a crucial role in offsetting these emissions by sequestering carbon, which helps to mitigate carbon buildup in the atmosphere. Carbon in wood harvested or latex from rubber plantation ends up in a variety of uses, from being sequestered in lumber in buildings or furniture for a century or more, to quickly being released into the atmosphere after the lifetime ends during decay process. It is consider four general categories for the fate of rubber end products: furniture, Medium Density Fibreboard, gloves and tyres. Figure 1.1 shows the carbon emission of rubber tree and rubber end products.